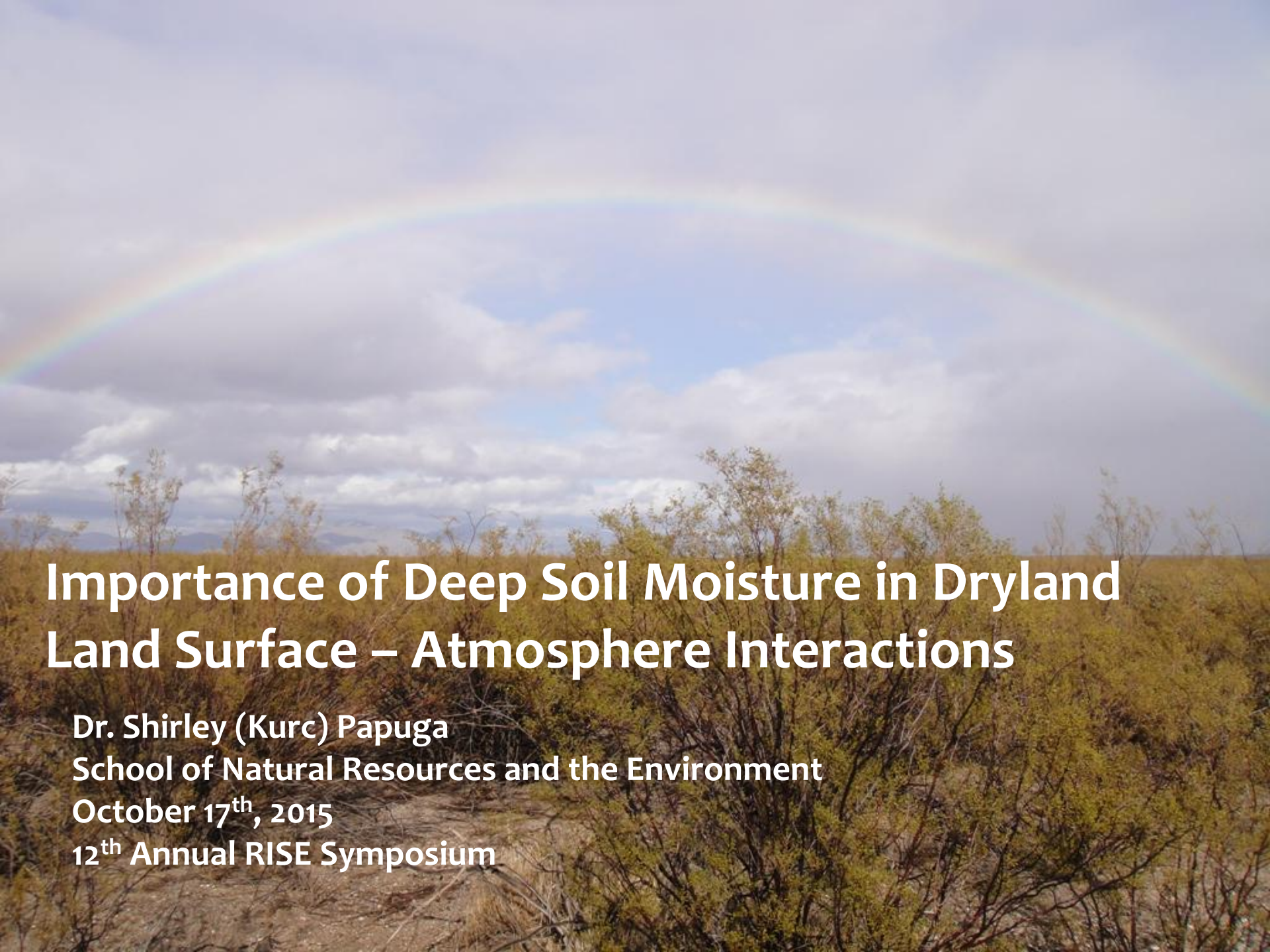
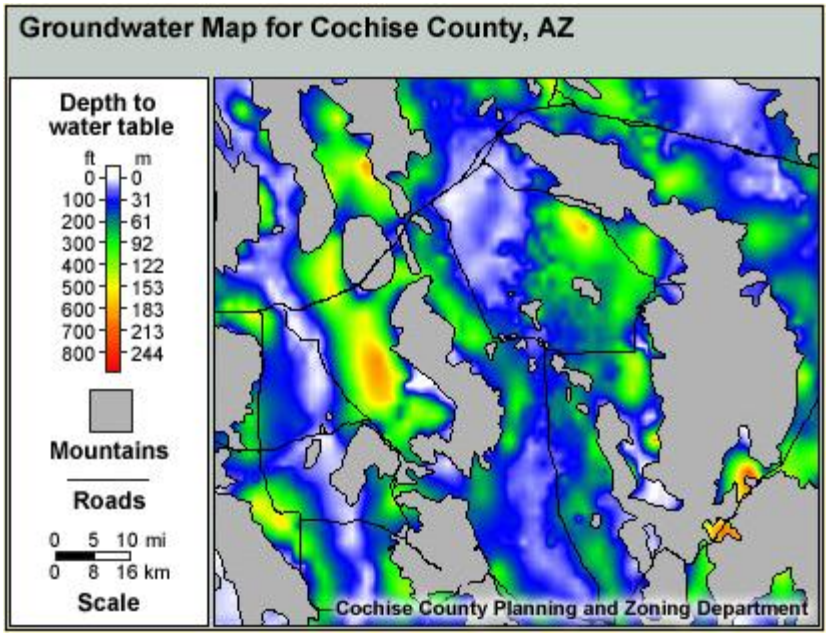


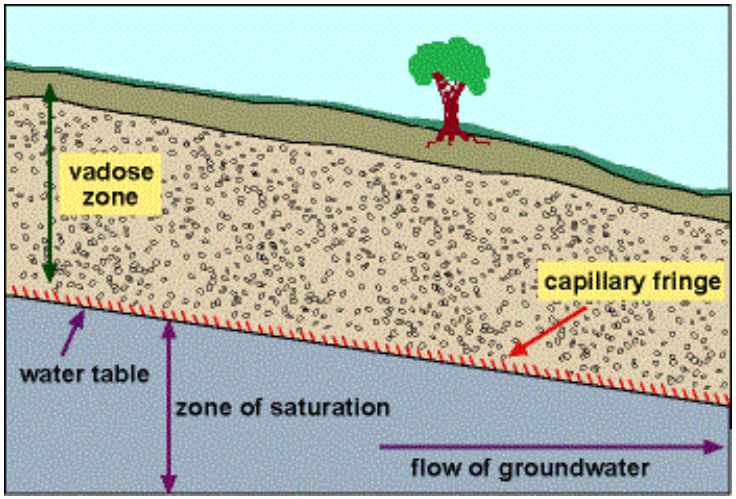
Importance of Deep Soil Moisture in Dryland Land Surface – Atmosphere Interactions

Dr. Shirley (Kurc) Papuga
School of Natural Resources and the Environment
October 17th, 2015
12th Annual RISE Symposium

Deep Soil Moisture ≠ Groundwater



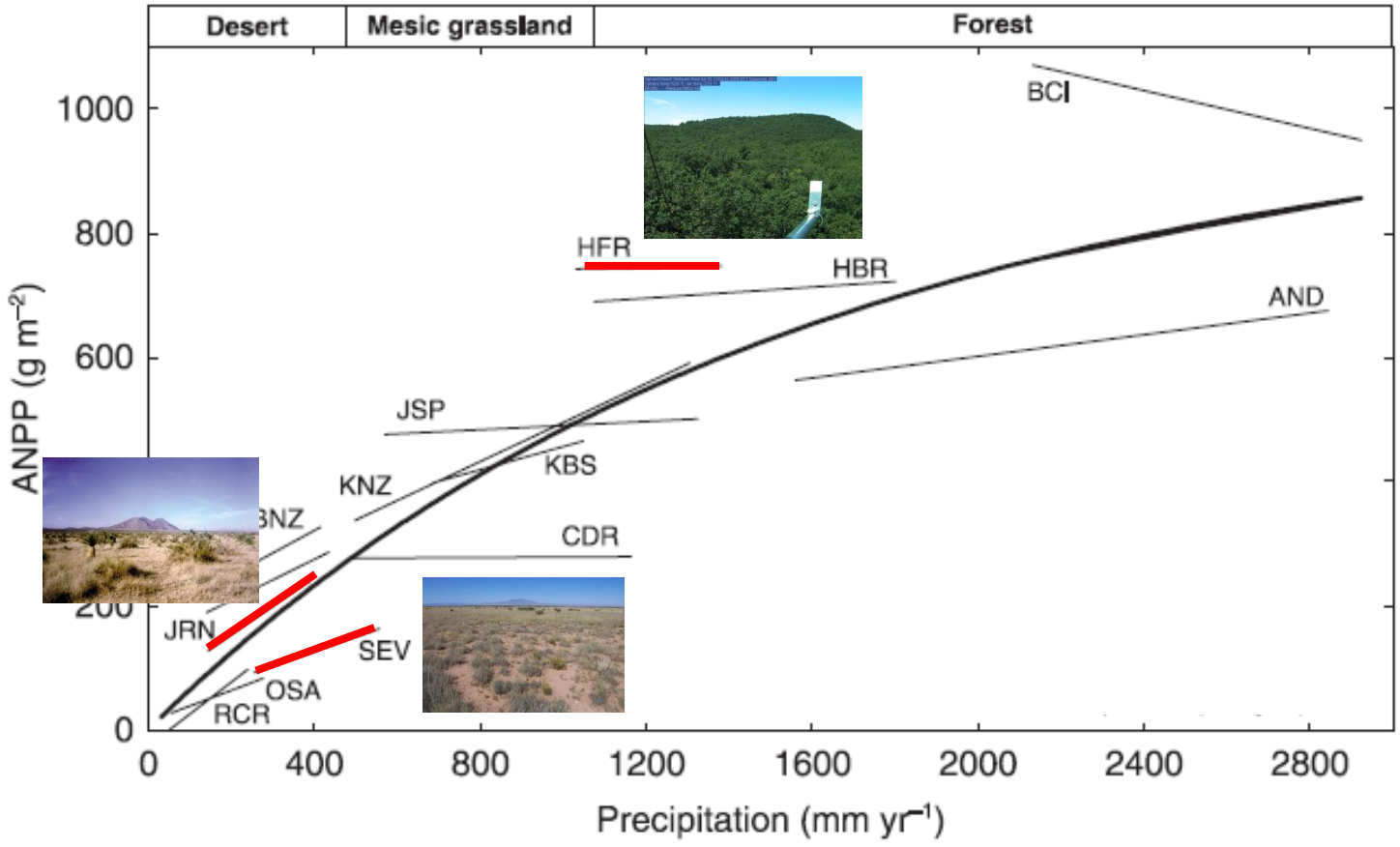
Depth to the water table often exceeds 100 ft / 30 m in drylands



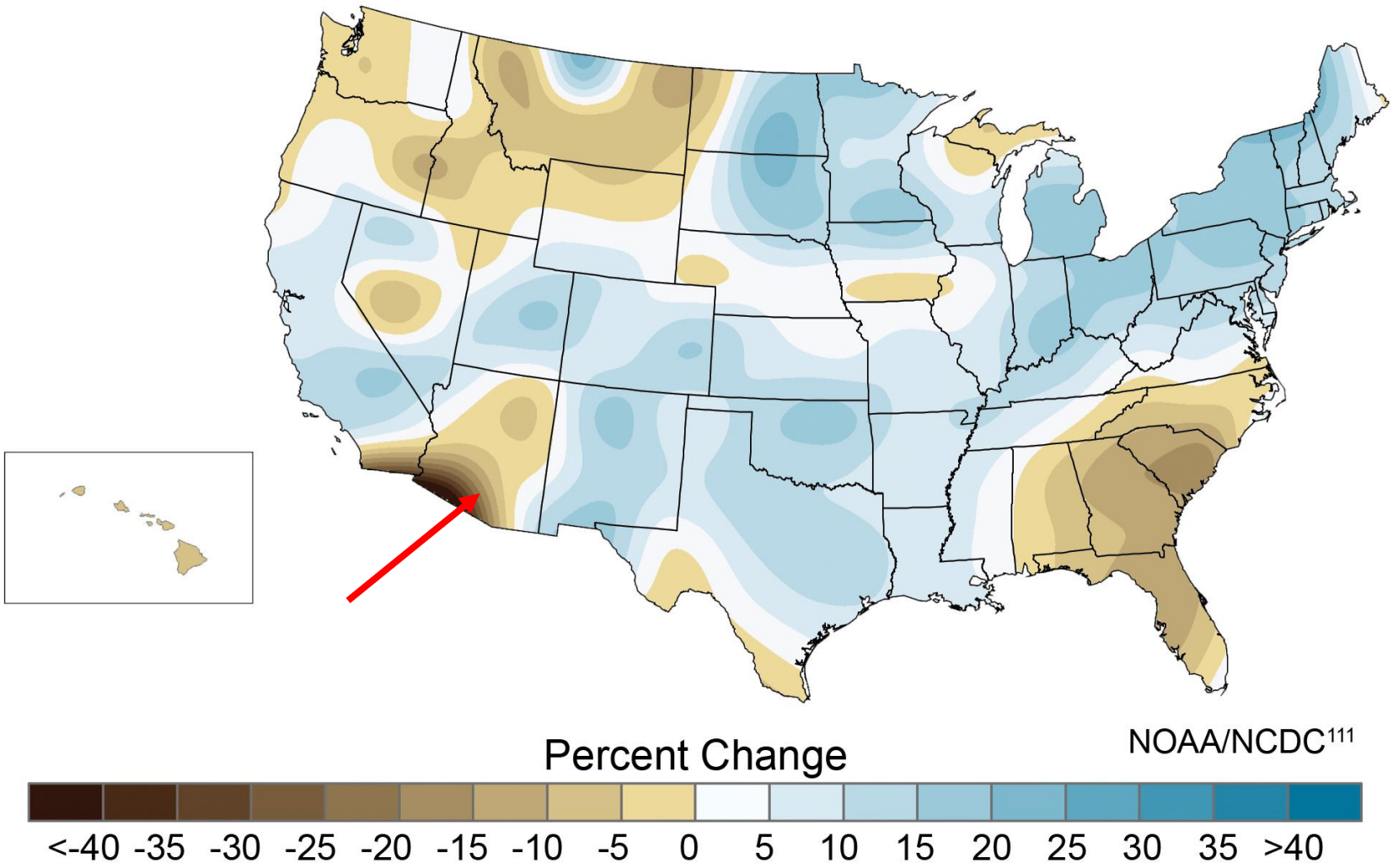
This very deep unsaturated zone means dryland plants are not accessing groundwater

Dryland plants depend on soil moisture provided by precipitation

Therefore, compared to other areas which receiver greater annual precipitation, drylands are highly sensitive to precipitation inputs



Fay, P.A., 2009 in New Phytologist and Huxman et al. 2004 in Nature.



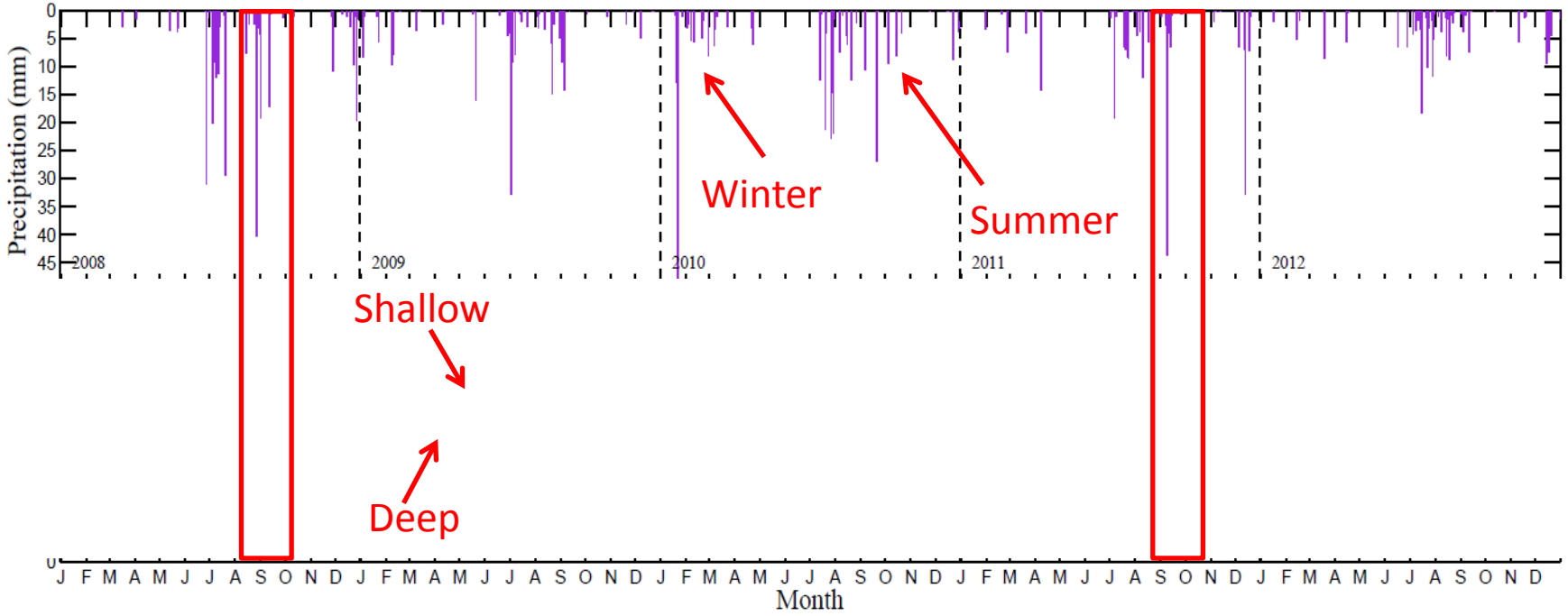
While U.S. annual average precipitation has increased about 5 percent over the past 50 years, there have been important regional differences as shown above.

Annual precipitation has been decreasing at the SRER-SRC over the past ~ 30 years

"Long-Term Precipitation Trends of Two Uniquely Water-Limited Ecosystems: Implications for Future Soil Moisture Dynamics" – Wehr and Papuga in prep

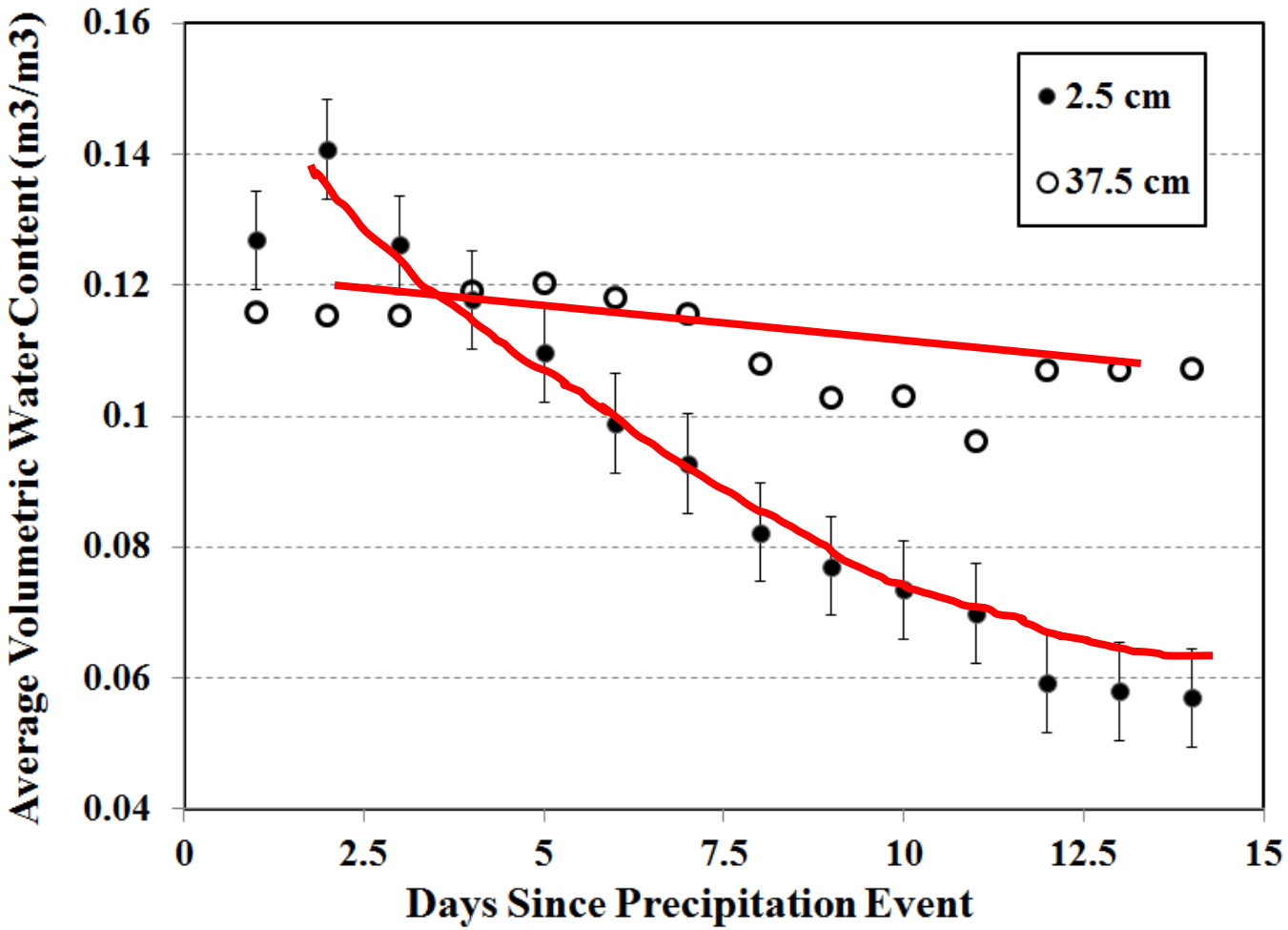
Precipitation at SRER-SRC is bimodal

Surface soil moisture responds to all storms, but deep soil moisture only available after large storms.



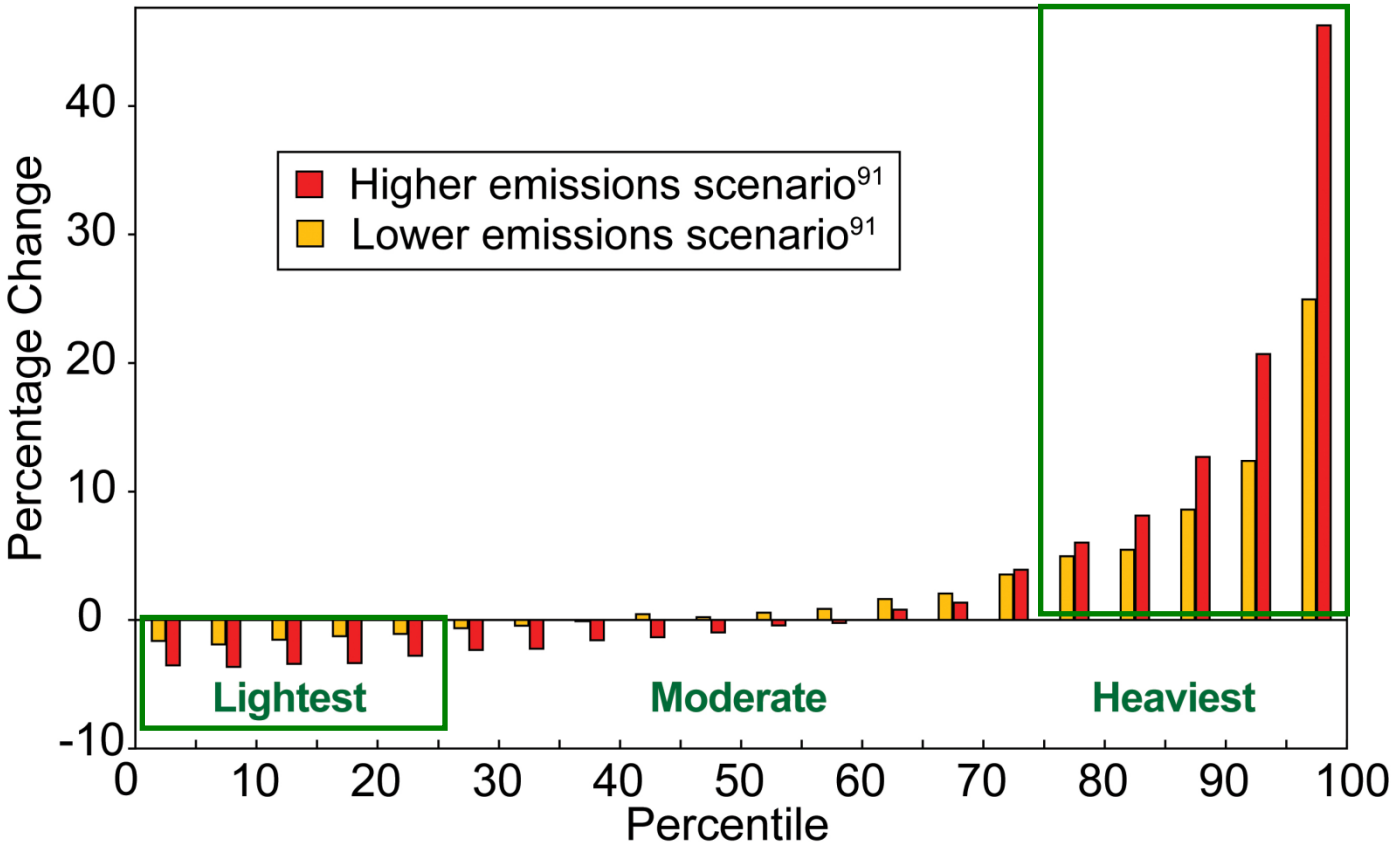
Most storms are small, with larger storms mostly occurring in the summer

Surface moisture is lost quickly, whereas deep moisture remains available in the soil for longer



Climate Change: *Precipitation*

Less small storms, more large storms

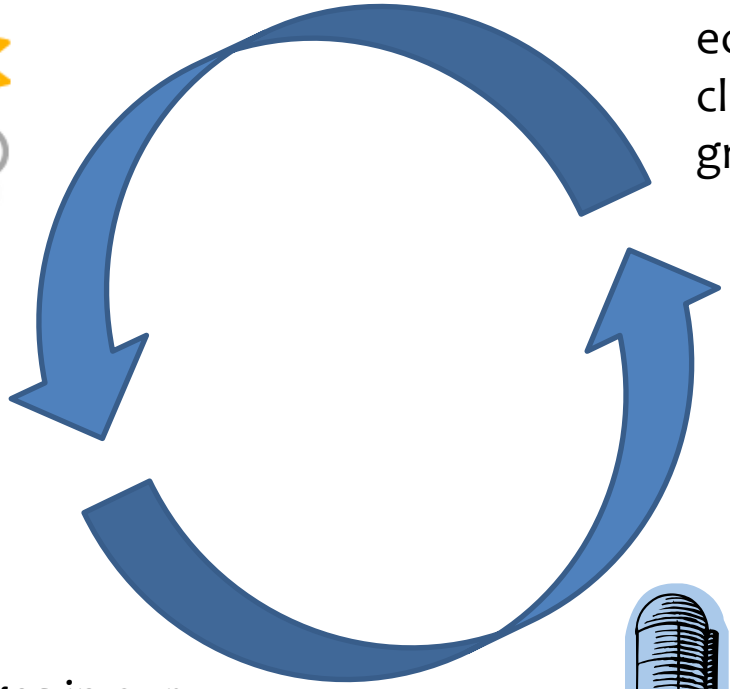


CCSP SAP 3.3[68]

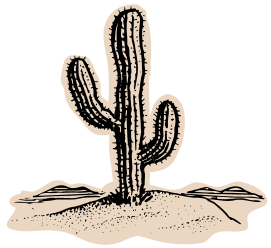




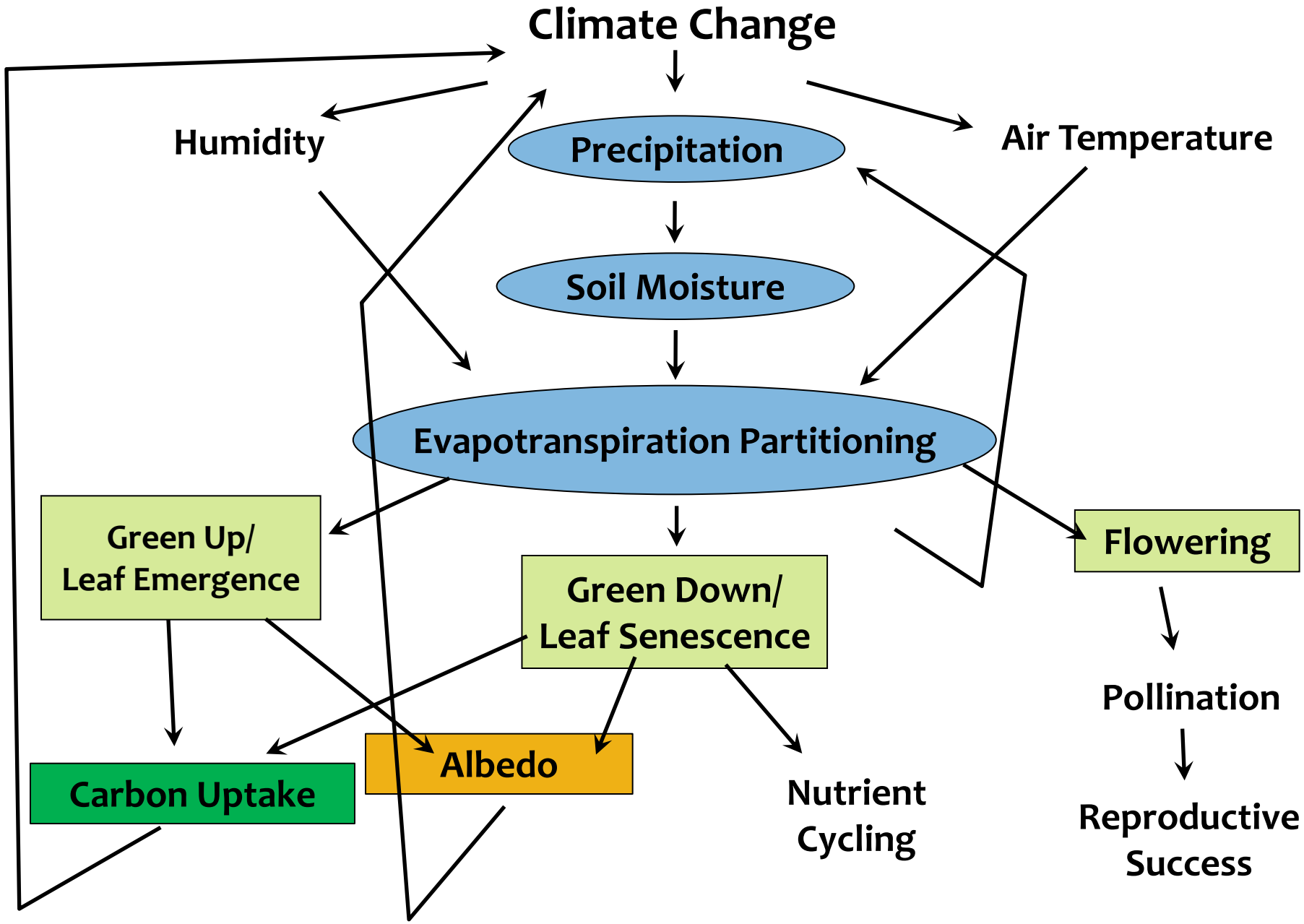




Predicting the response of our ecosystems to changes in climate is one of today's greatest challenges



Predicting how changes in our ecosystems affect the climate system is another of our greatest challenges


Climate Change
Humidity
Precipitation
Air Temperature
Soil Moisture
Evapotranspiration Partitioning
Green Up/
Leaf Emergence
Green Down/
Leaf Senescence
Flowering
Pollination
Albedo
Carbon Uptake
Nutrient
Cycling
Reproductive
Success

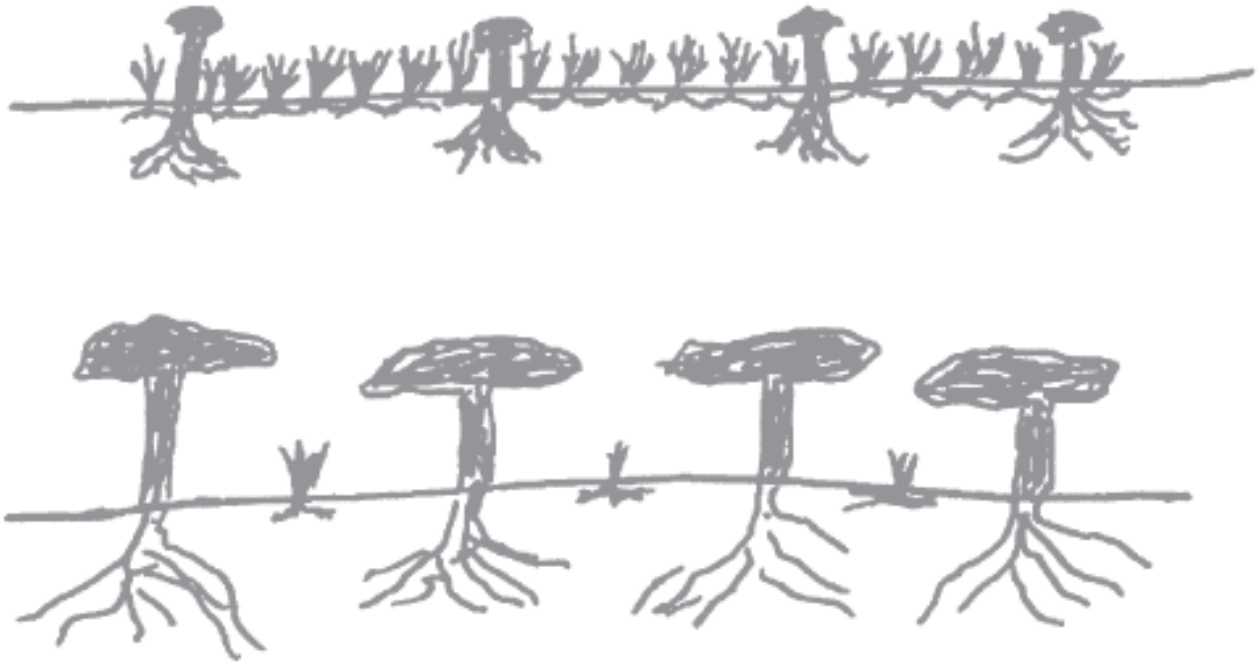
Work from my research group has shown:

- Transpiration in dryland ecosystems (grassland and shrubland) is triggered by deep soil moisture
  [Kurc and Small 2007, Cavanaugh et al 2011]

- Carbon uptake in dryland ecosystems (grassland and shrubland) is triggered by deep soil moisture
  [*Kurc and Small 2007, Kurc and Benton 2010]*

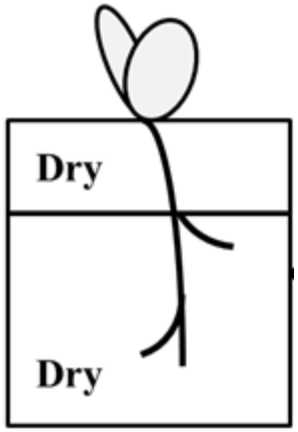
Walter's Two-Layer Hypothesis

A root-based niche-partitioning hypothesis of tree-grass coexistence positing that shallow rooted grasses exploit soil moisture in shallow layers while deep rooted trees have exclusive access to soil moisture in deep layers



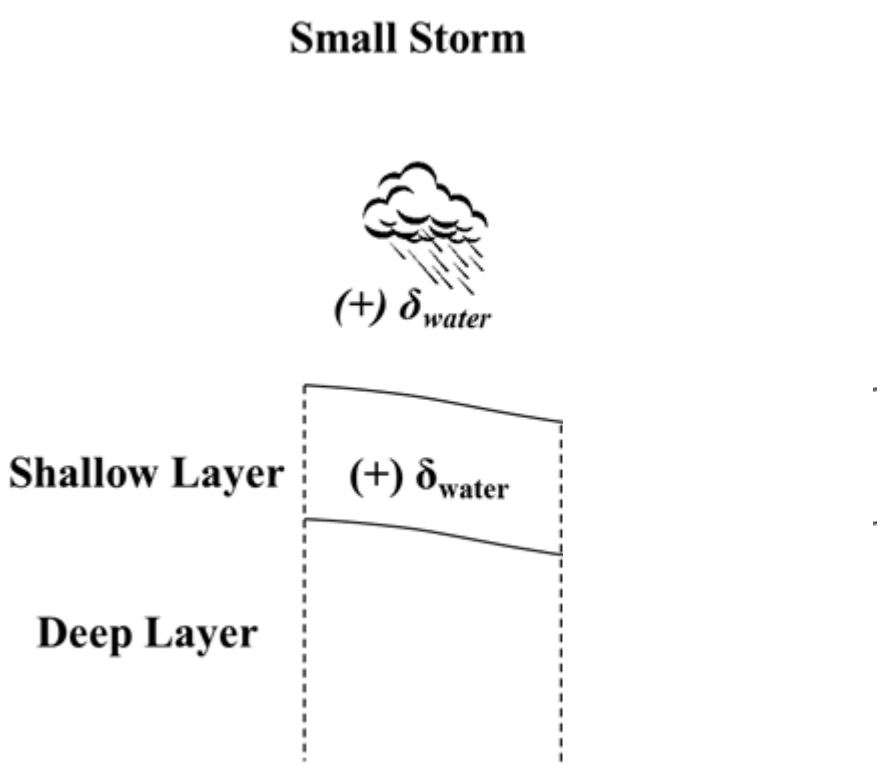
http://gerrymarten.com/human-ecology/chapter06.html

Hydrologically-Defined Two-Layer Framework



Stable Water Isotopes In Two-Layer Framework

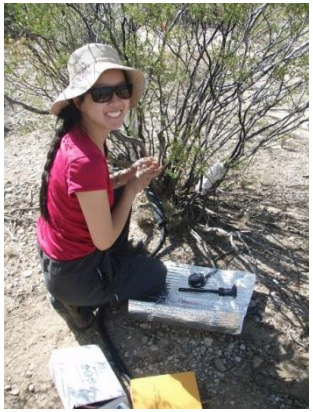
We hypothesized that the shallow and deep soil layers are isotopically distinct –through precipitation and evaporation



Evaporation further enriches δ_{water} values in the shallow layer

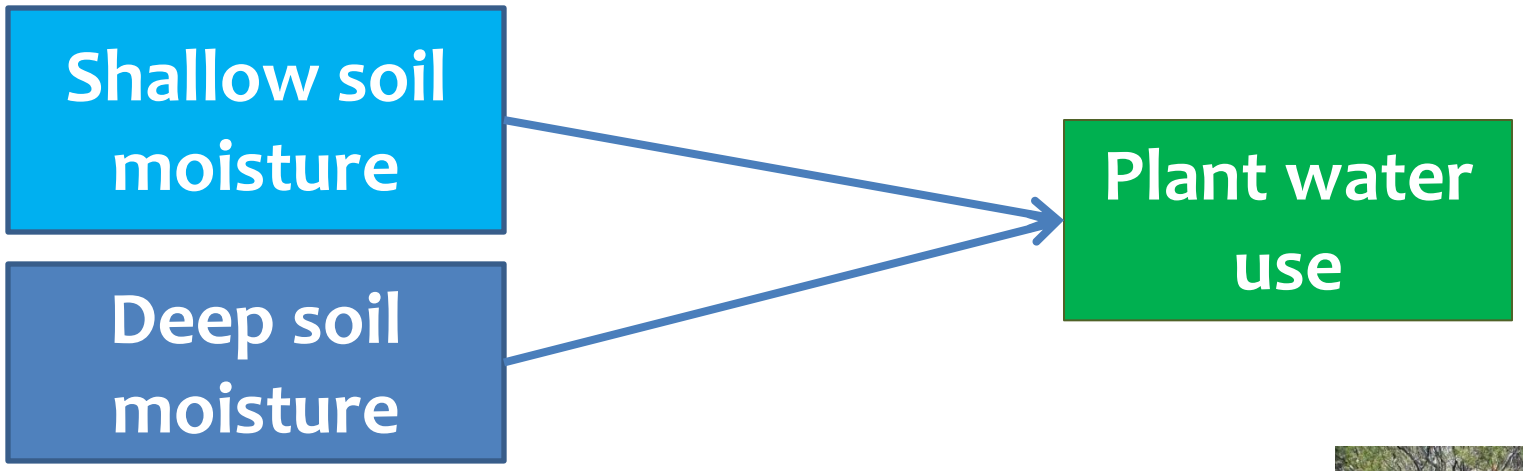
Small storms are heavier in $\delta^{18}O$ and $\delta^{2}H$

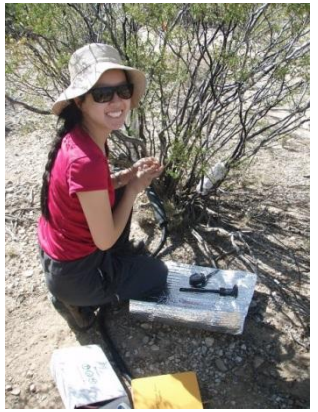
Large storms are more depleted in $\delta^{18}O$ and $\delta^{2}H$



Stable Water Isotopes In Two-Layer Framework

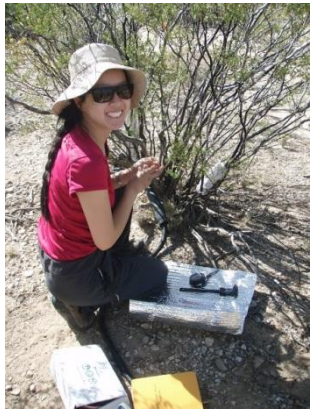
We further hypothesized that we could identify the source water for plants because the layers were isotopically distinct.





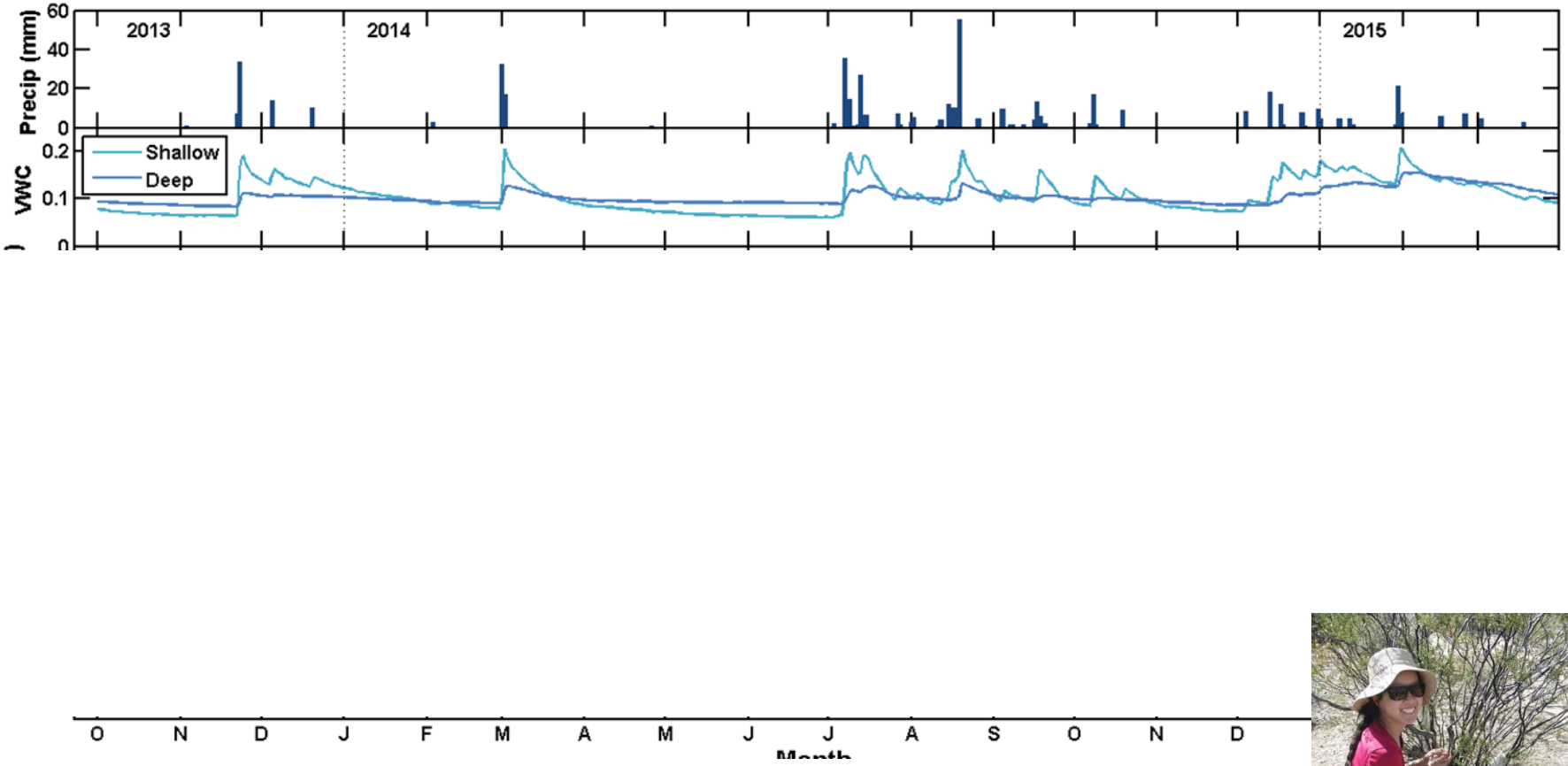
Methods

- **Micrometeorological and Eddy Measurements**
  - Evapotranspiration, Precipitation
- **Soil Moisture Measurements**
  - Multiple Depths Averaged to Shallow and Deep
- **Sap Flow System**
  - Transpiration
- **Isotopic Field Campaign (2014&2015)**
  - Soil, Plant, and Precipitation Samples
  - Lab Analyzed with Picarro Induction Module



Stable Water Isotopes In Two-Layer Framework

Are shallow and deep soil layers are isotopically distinct?

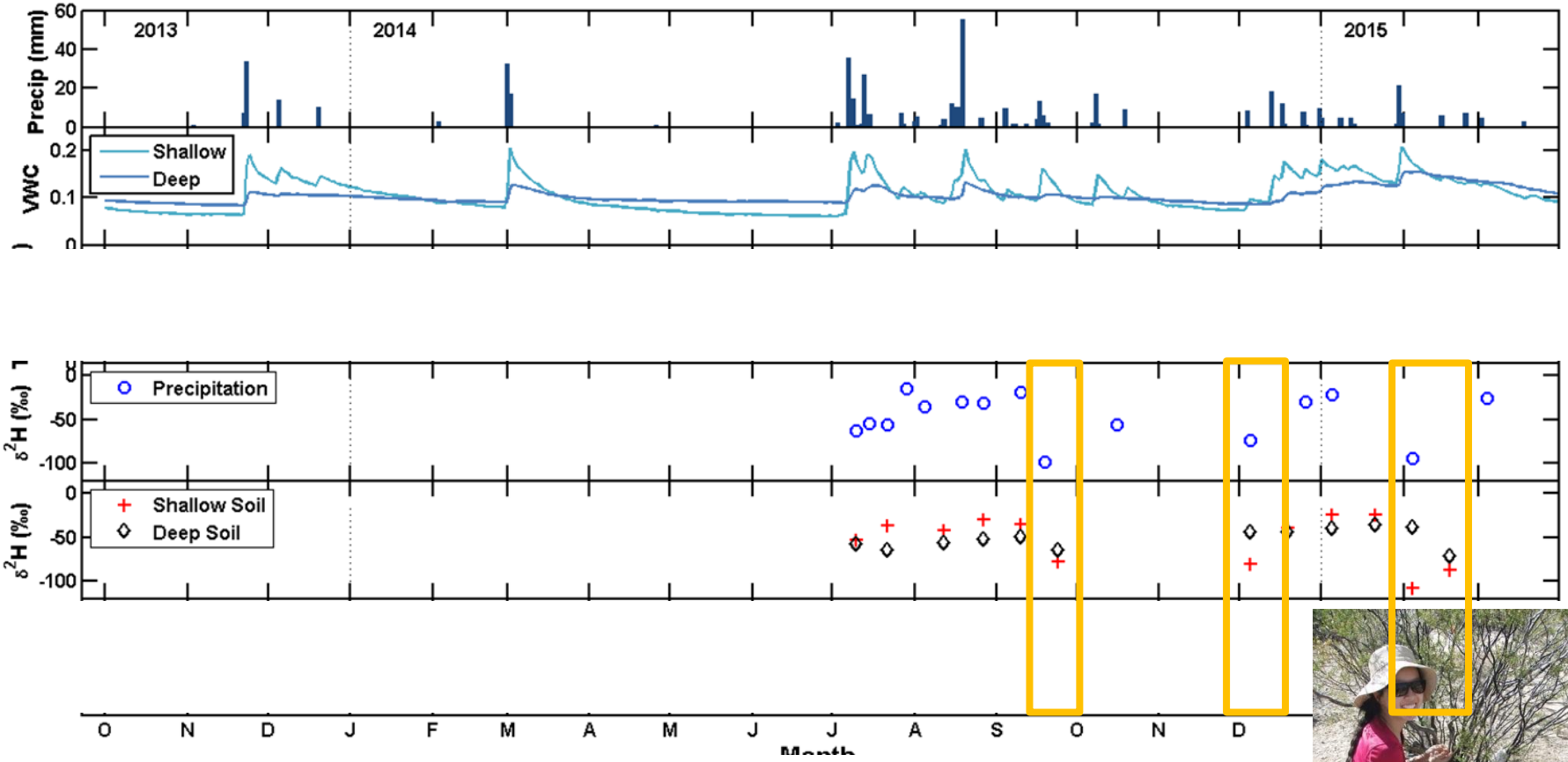


Shallow soil is more enriched in δ^2H

Except after storms depleted in δ^2H

Stable Water Isotopes In Two-Layer Framework

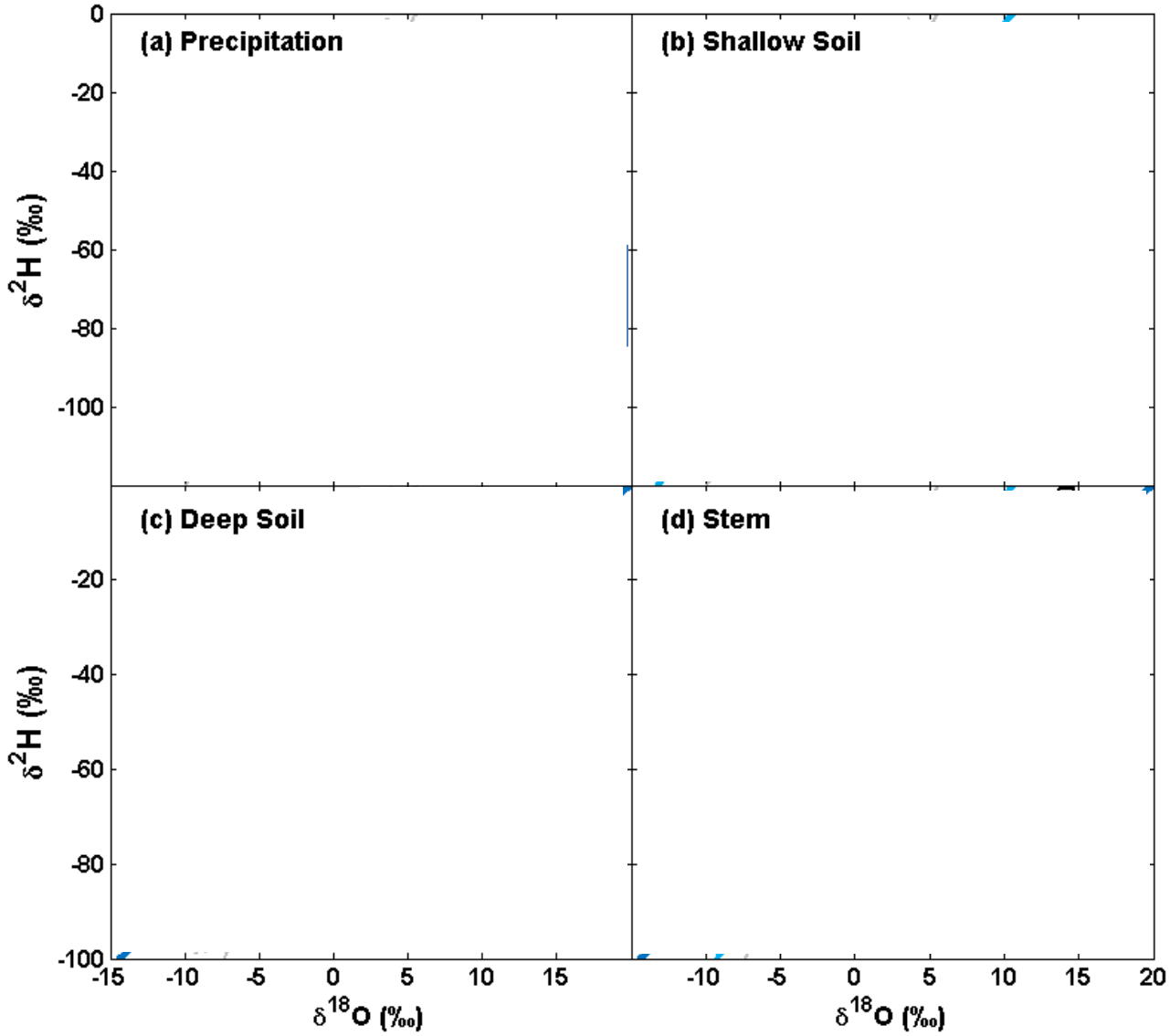
Are trends in shallow or deep moisture expressed in the plants?



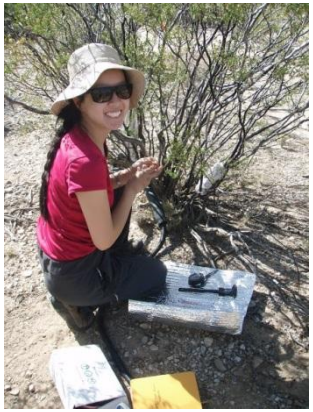
We can see water from these isotopically light storms moving through the soil and being taken up by plants

Stable Water Isotopes In Two-Layer Framework

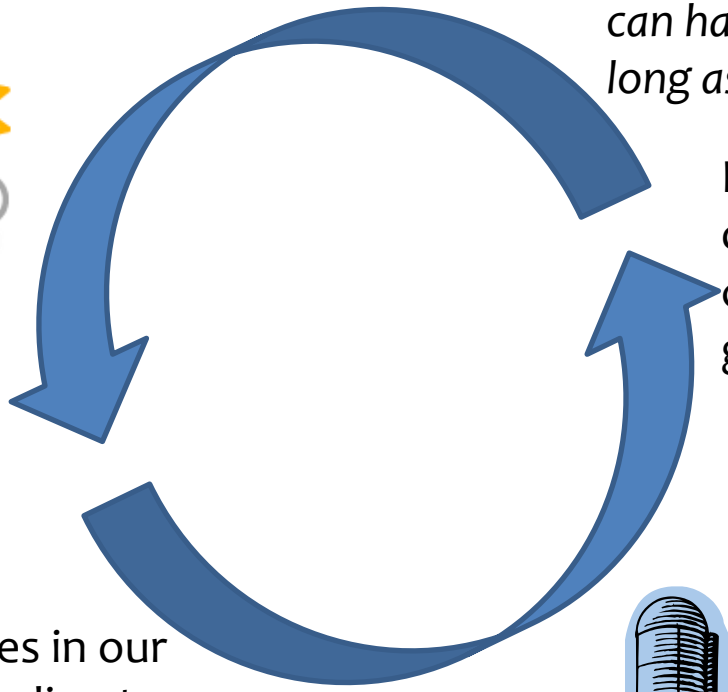
Are trends in shallow or deep moisture expressed in the plants?



Stems fall along the deep soil regression line: plants are isotopically more similar to deep moisture!

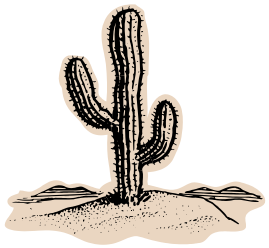


Desert shrublands depend on rainfall events capable of wetting the deep soil layers *suggesting they can handle less overall precipitation as long as there are still big events*

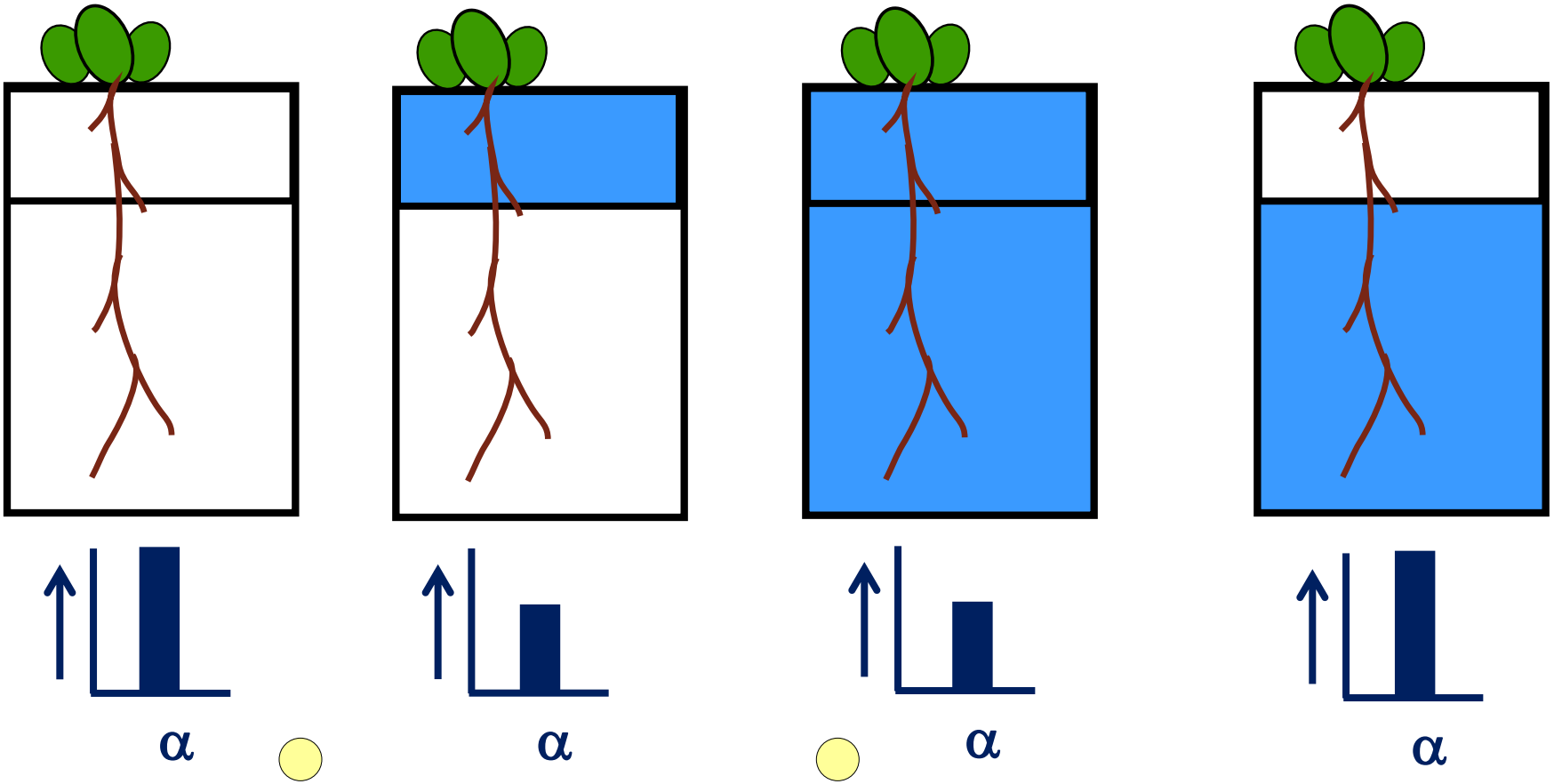


Predicting the response of our ecosystems to changes in climate is one of today's greatest challenges

Predicting how changes in our ecosystems affect the climate system is another of our greatest challenges



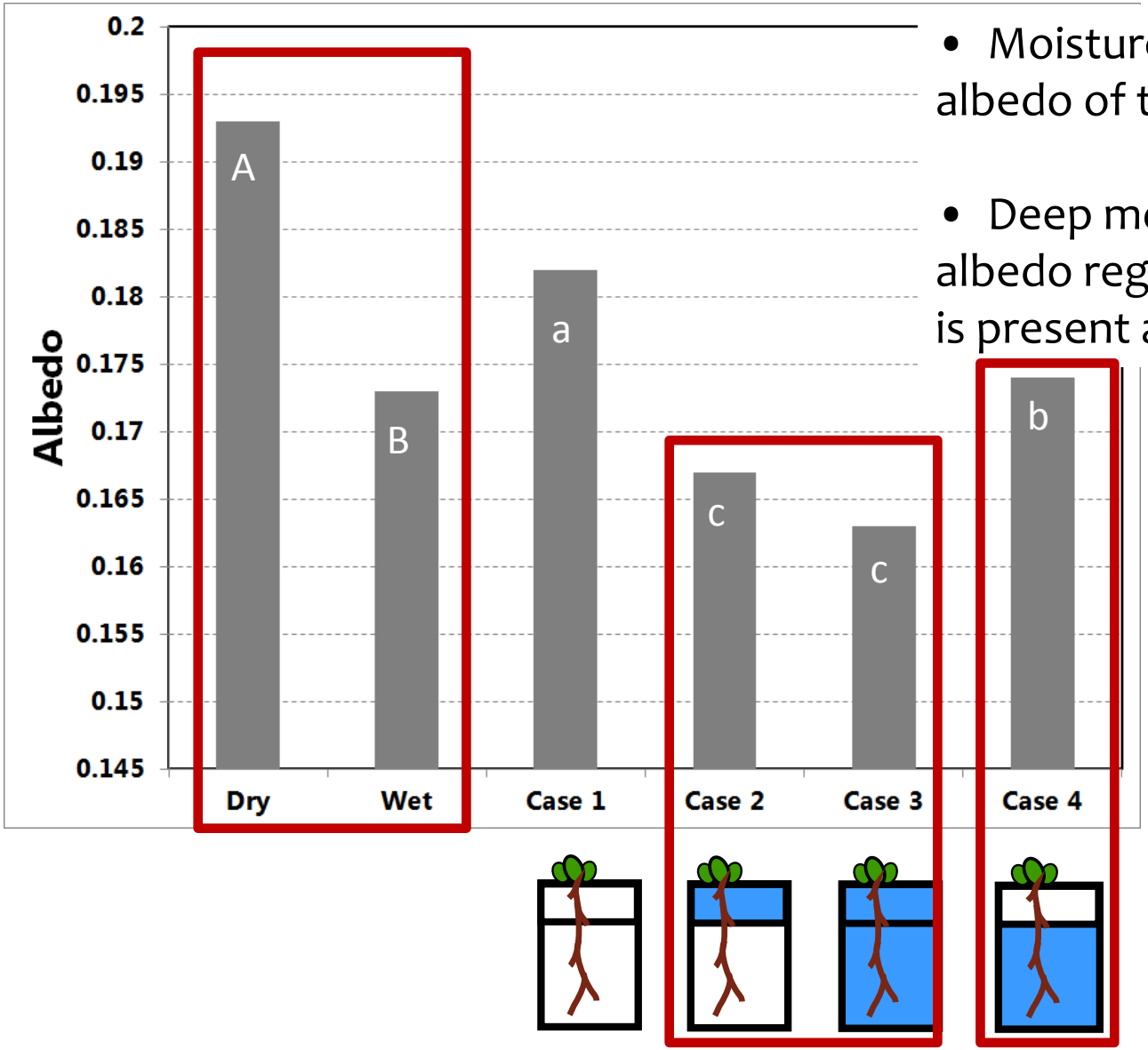
Albedo in Two-Layer Framework



Lighter,
More
Reflective

Darker,
Less
Reflective

Albedo in Two-Layer Framework

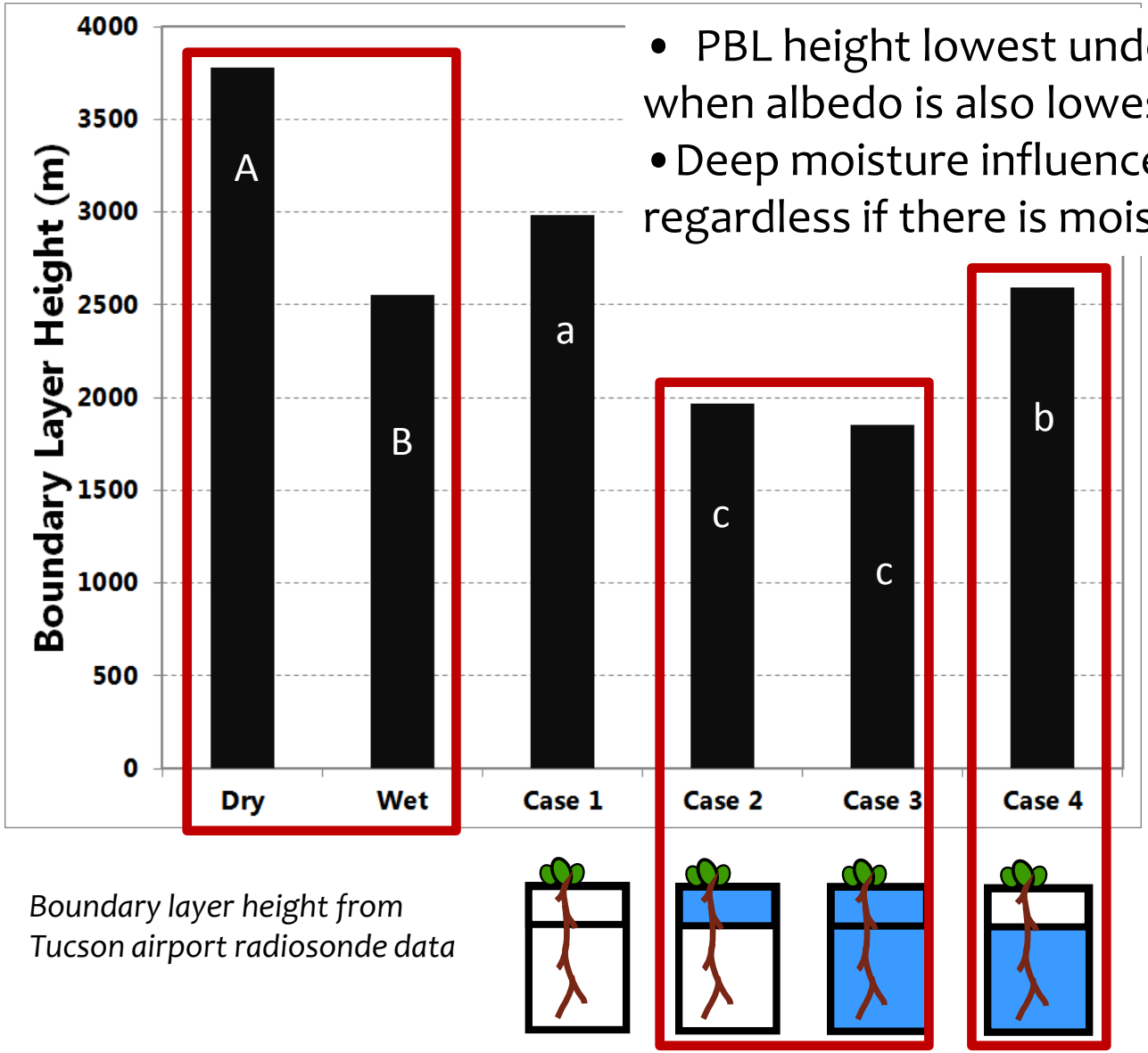


- Moisture decreases the albedo of the ecosystem.
- Deep moisture influences albedo regardless if moisture is present at the surface

?!

Sanchez-Mejia , Z.M. and S.A. Papuga, Water Resources Research, 2014

Albedo in Two-Layer Framework



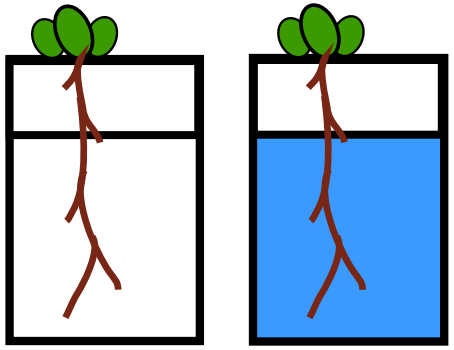
- PBL height lowest under wet conditions when albedo is also lowest
- Deep moisture influences PBL height regardless if there is moisture at the surface

?!

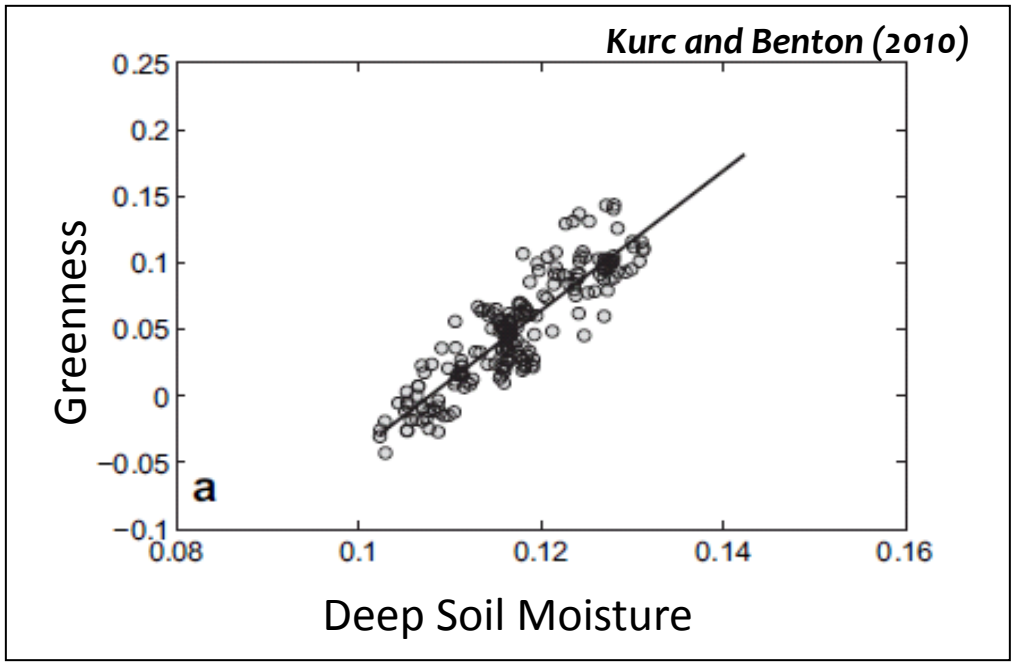
Boundary layer height from Tucson airport radiosonde data

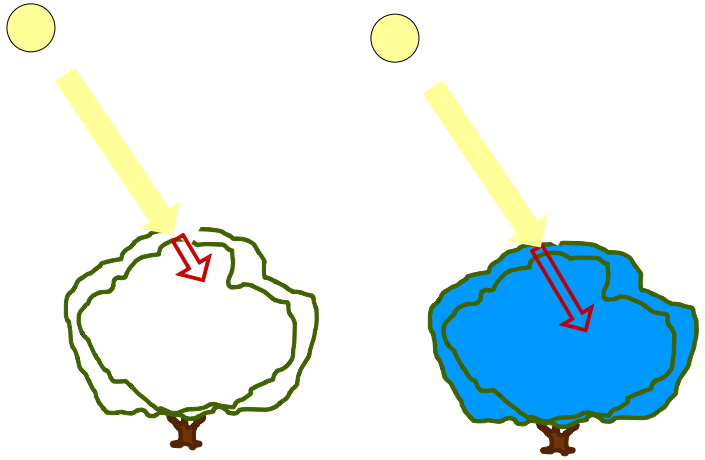
Sanchez-Mejia , Z.M. and S.A. Papuga, Water Resources Research, 2014

Deep moisture influence on albedo



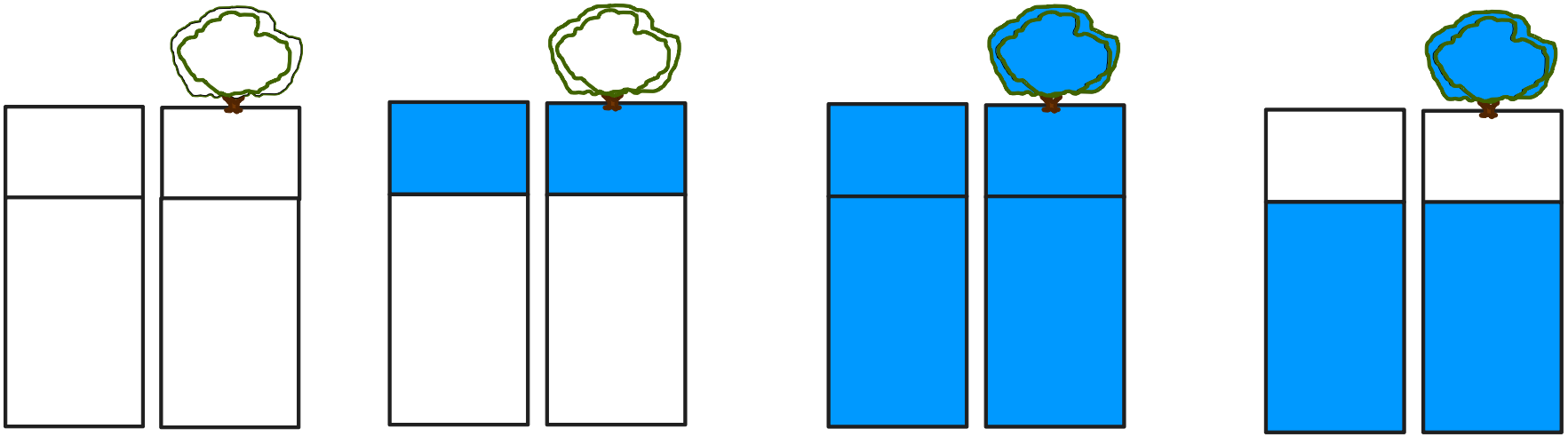
- shrub "greenness" controlled by deep soil moisture
- wet "green" canopies are darker and less reflective





Sanchez-Mejia , Z.M., S.A. Papuga, et al., Water Resources Research, 2014

Deep moisture influence on albedo



Surface moisture not enough to support plants

Deep moisture enough to support plants

Both High

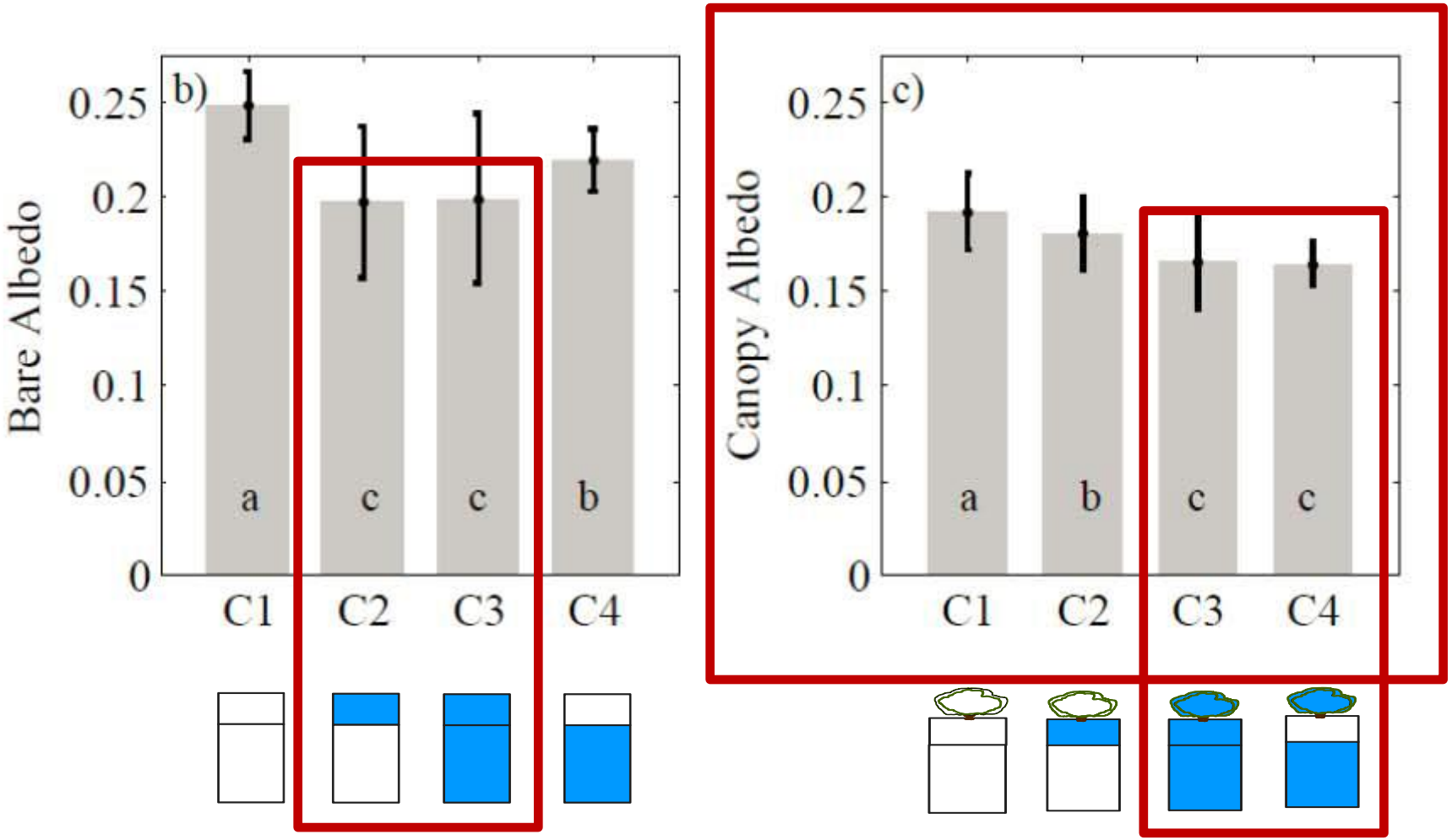
Bare Low Canopy High

Both Low

Bare High Canopy Low

Sanchez-Mejia , Z.M., S.A. Papuga, et al., Water Resources Research, 2014

Deep moisture influence on albedo



- Canopy albedo is always lower than bare albedo
- A "wet" surface, whether soil or vegetation, always has the lowest albedo

Sanchez-Mejia , Z.M., S.A. Papuga, et al., Water Resources Research, 2014

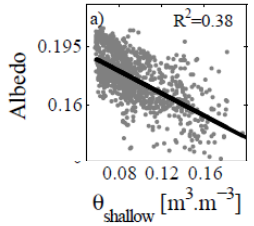
Now we ask…

Can we use empirical relationships between soil moisture, albedo, and planetary boundary layer height to evaluate consequences of future precipitation changes?

Sanchez-Mejia , Z.M. and S.A. Papuga in prep for Journal of Hydrometeorology

So we propose…

A simple modeling approach:



Daily Precipitation is generated using stochastic process

Shallow soil moisture calculated using two-layer bucket model

Deep soil moisture calculated using two-layer bucket model

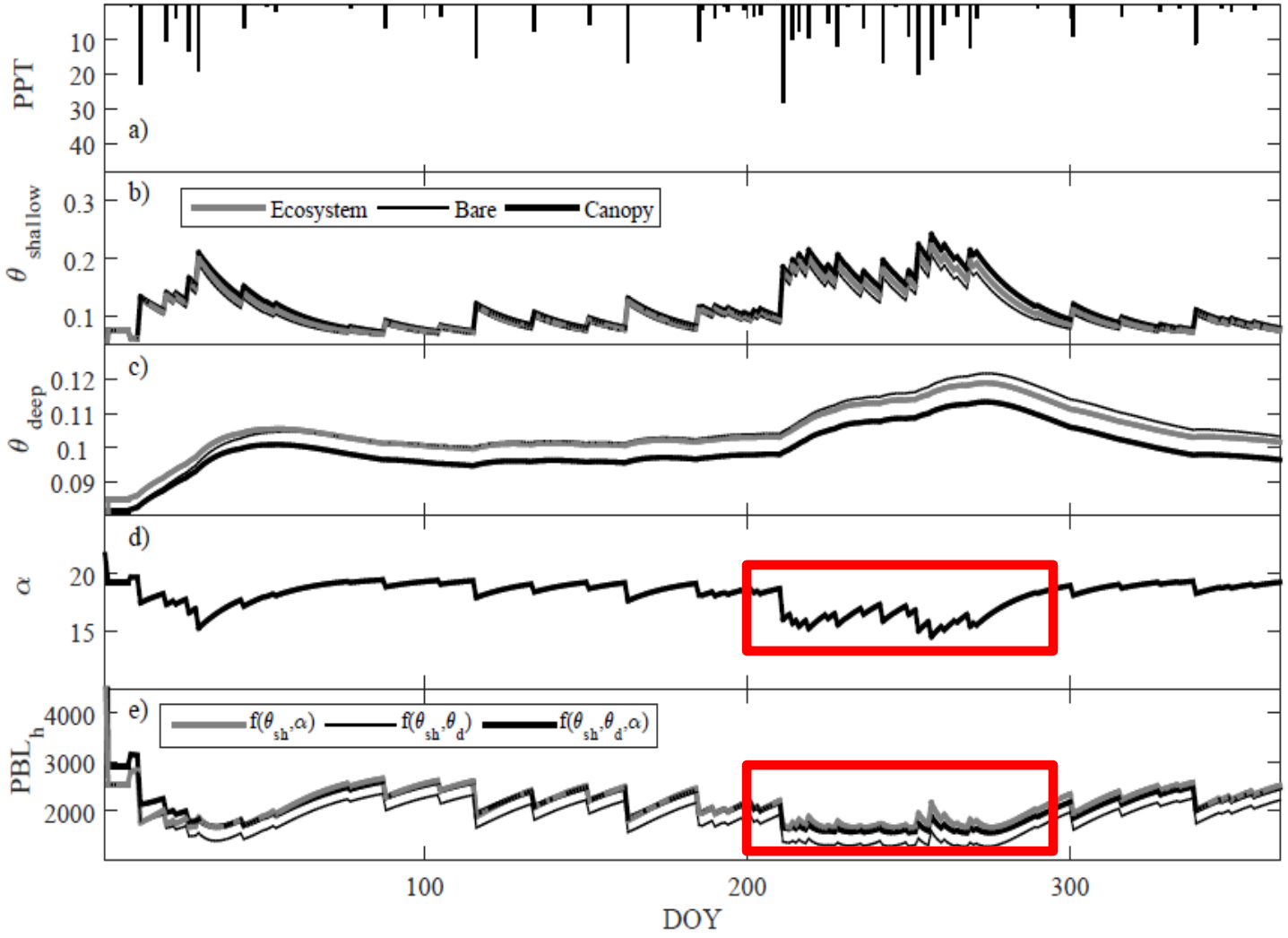
Albedo calculated from linear relationship with shallow soil moisture

***PBL*$_h$ is calculated from shallow soil moisture, deep soil moisture, and albedo using polynomial relationships**

Sanchez-Mejia , Z.M. and S.A. Papuga in prep for Journal of Hydrometeorology

Results from our empirical model:

Current regime: Rains ~ every 3 days in summer, 6 days in winter



Annual values:

358 mm

0.114 $m^3 m^{-3}$

0.104 $m^3 m^{-3}$

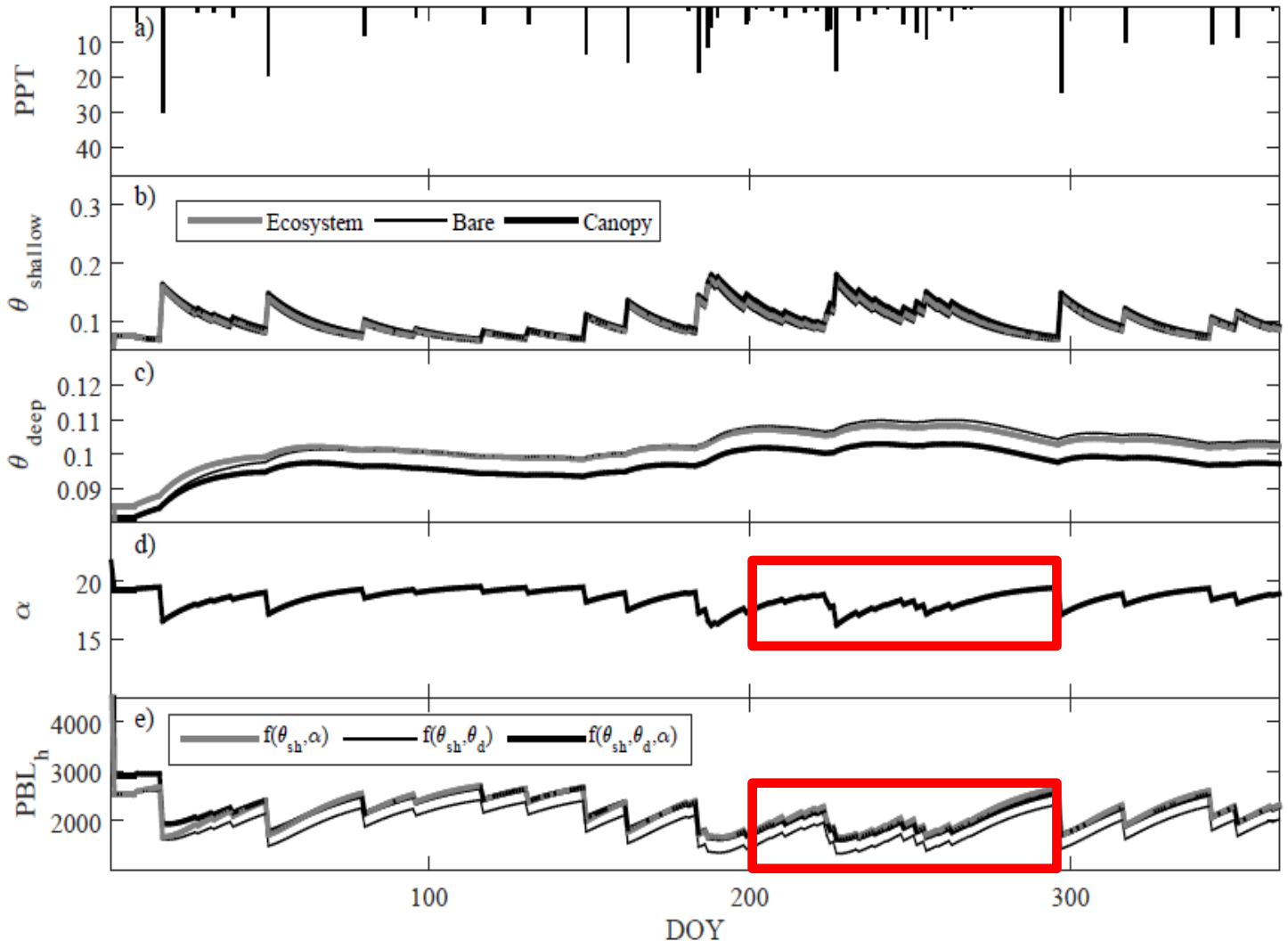
18.1 %

2118 m

Sanchez-Mejia , Z.M. and S.A. Papuga in prep for Journal of Hydrometeorology

Results from our empirical model:

Example New regime: Decrease in Overall Precip, Increase in Frequency



Annual values:

286 mm

0.098 $m^3\ m^{-3}$

0.101 $m^3\ m^{-3}$

18.52 %

2217 m

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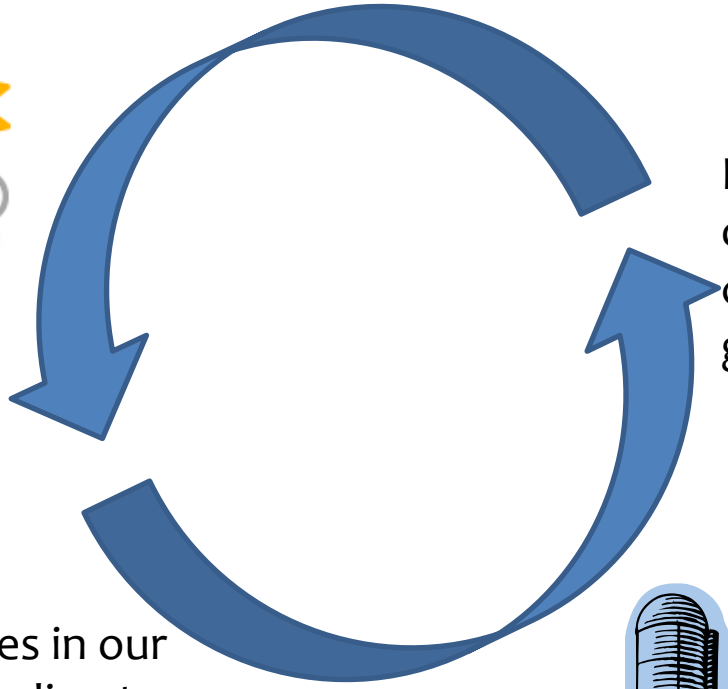

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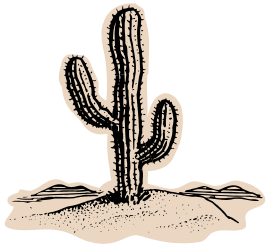

Predicting how changes in our ecosystems affect the climate system is another of our greatest challenges

Greening in shrublands leads to decreased albedo and lower boundary layer *potentially generating better conditions for rainfall*

[Sanchez-Mejia and Papuga 2014; Sanchez –Mejia et al. 2014]

Acknowledgments

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Eric Small
Andrew Neal
Zulia Mayari Sanchez Mejia
Daphne Szutu
Rachel Wehr

THANK YOU!

Questions?